# The future of SENSEI

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University of Buenos Aires
IFIBA - CONICET/FNAL
for the SENSEI* Collaboration
@ New Perspectives 2020

*Sub-Electron-Noise Skipper-CCD Experimental Instrument

# The SENSEI Collaboration

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**U. Oregon:**

- T.-T. Yu

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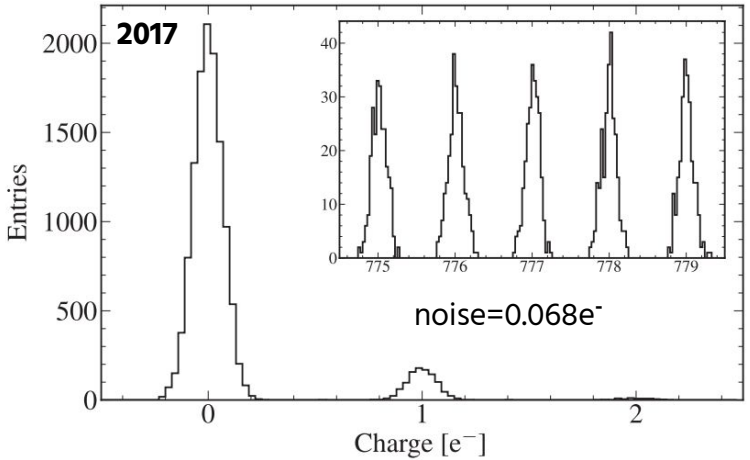
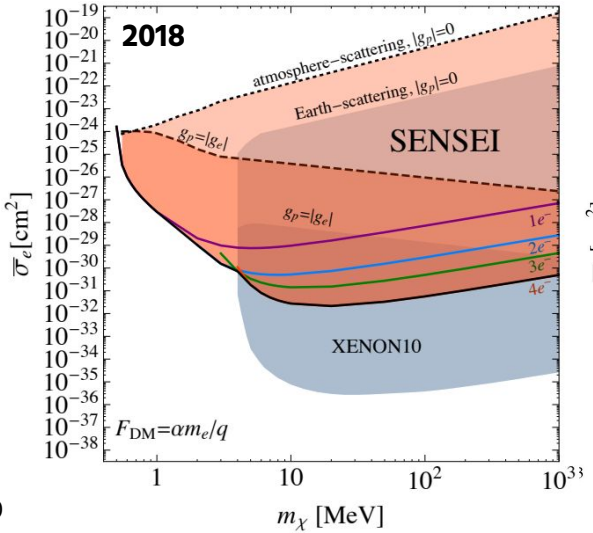
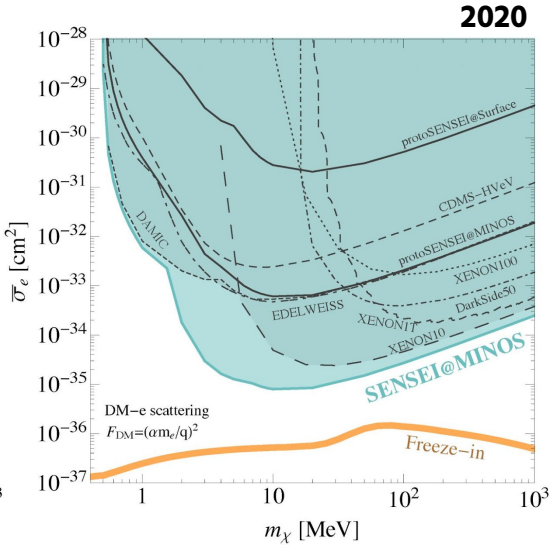
**& leveraging R&D support from Fermilab**

# Recent news

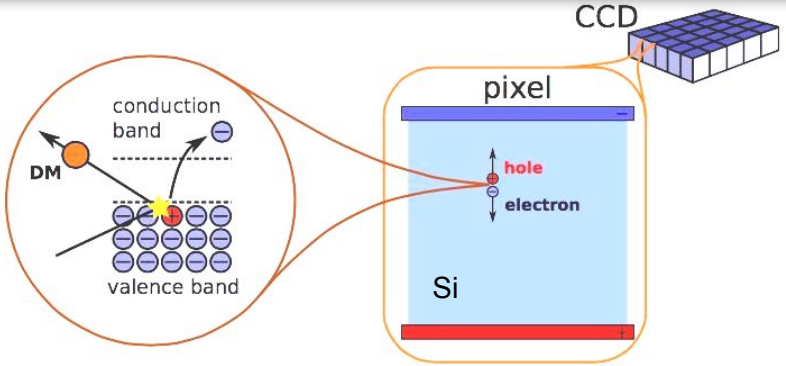
| | |
|---|---|
| 2017 | Demonstration of 0.068e- noise in SENSEI prototype [1]. |
| 2018 | DM search with surface run of SENSEI prototype [2]. |
| 2019 | DM search with underground run of SENSEI prototype [3]. |
| April 2020 | DM search with underground run of SENSEI first science grade Skipper-CCD [4]. |



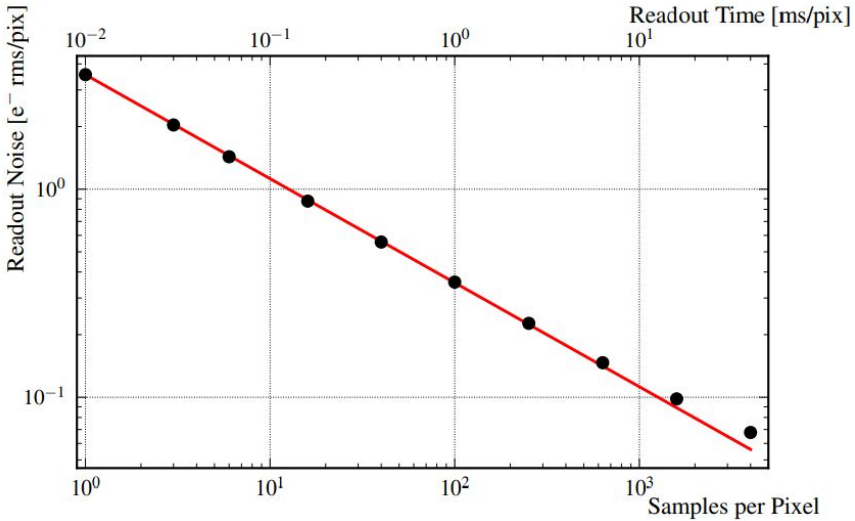



# Electron recoils for sub-GeV DM in Skipper-CCDs

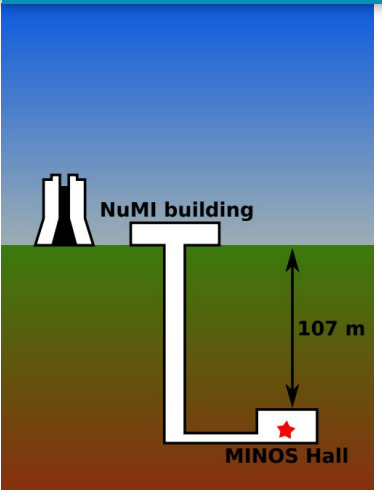



- Benchmark models: DM-e⁻ scattering, DM absorption
- Silicon CCDs as **ionization** detectors
- Range **mass**: 1-1000 MeV (~eV on DM absorption)
  - Very small **signals**
    - Very low energy **threshold**

- *Skipper* technology allows to read repeatedly the *same pixel* to achieve **sub-electron noise**
- ~2e⁻ readout noise and **<0.1e⁻** using *skipper* technology
- **Low energy** threshold **down to** 1.2eV (Si band gap)

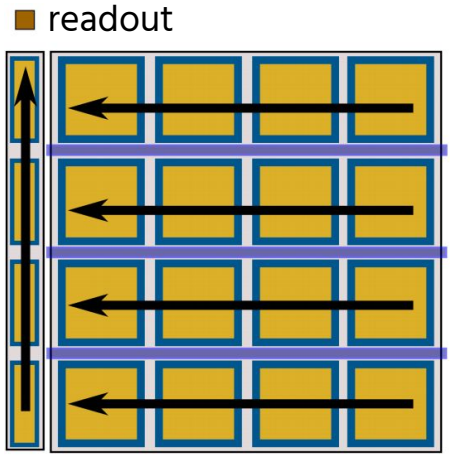


# Electron recoils for sub-GeV DM in Skipper-CCDs



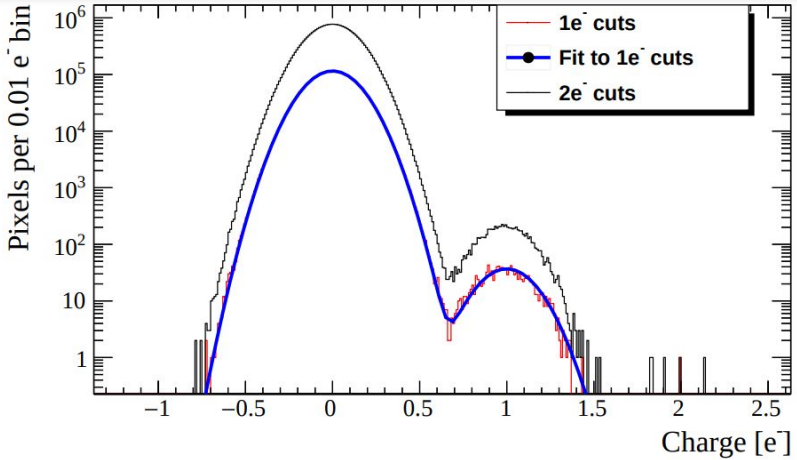

- Setup **~107m below surface** at shallow underground MINOS site @FNAL.
- This reduces muon background while lead shield reduces environmental gamma radiation
- Operated at **135K** and high-vacuum regime to reduce dark current without generating CTI

- ~**2g** per device of high-resistivity fully-depleted **silicon**
- ~**5.5Mpixels** of 15x15x675 $\mu m^3$ each
- >**99.9%** charge collection and transfer efficiency
- Long exposures, long readout times, very low readout noise
- Operated with specifically designed readout electronics (**LTA board**)



# Our last result: data and specifics

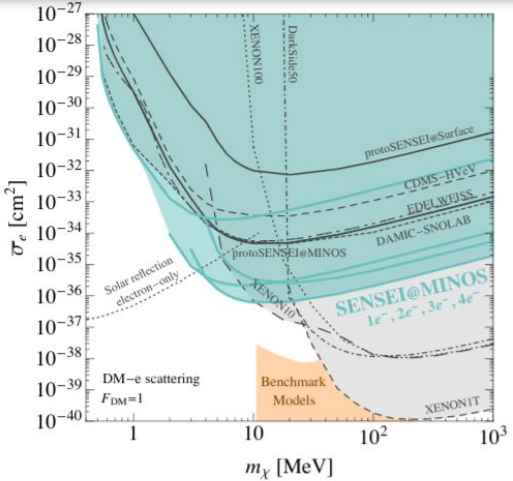
- Blinded dataset of 22 images, Feb 25 - Mar 20
  →Total exposure: **19.926 gram-days**
- 300 *skipper* samples → **0.14e⁻** readout noise
- **x20 more mass** than 2019 (x10-15 effectively)

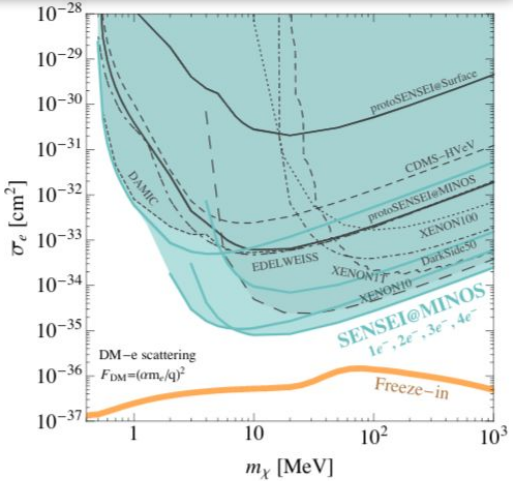


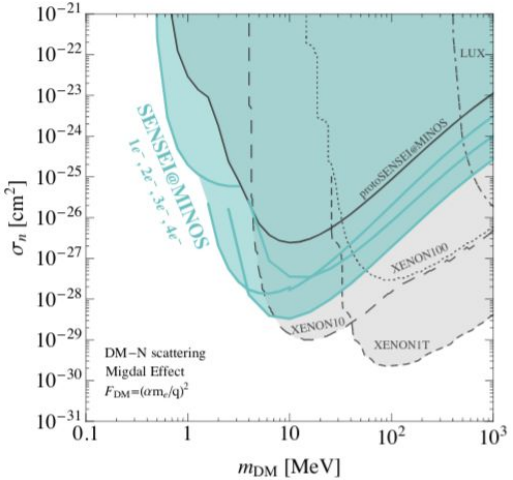

- Background as low as ~3400 events/kg/keV/day (**~3 times** less than 2019)
- ~~DC rate~~ Single-electron event rate as low as ~$1.6\times10^{-4}$ e⁻/pixel/day or ~**450 events/gram/day** (**~20 times** less than 2019)
- x(**8-35**) more effective exposure (depending on e⁻ channel)

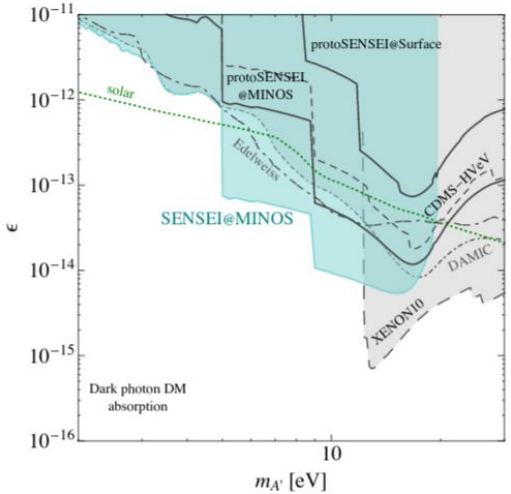
# Our last result: limits on DM

- World-leading constraints on **DM-e$^-$ scattering** for light mediator (top right) and heavy mediator (top left), up to 10 MeV.
- World-leading constraints for **DM-nucleus scattering** (bottom left) through light mediator from 600 keV to 5 MeV (Migdal Effect [5]).
- World-leading constraints for **DM absorption on electrons** (bottom right) from 1.2 to 12.8 eV.



# Perspectives

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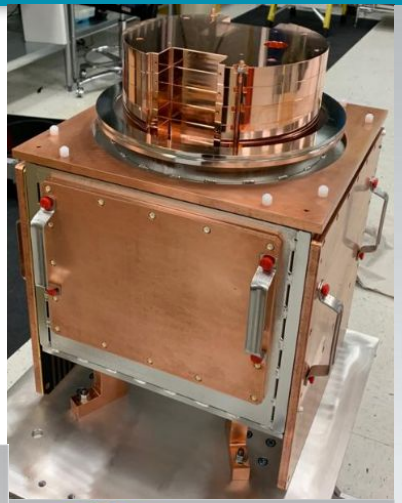
| 2021 | ??? |

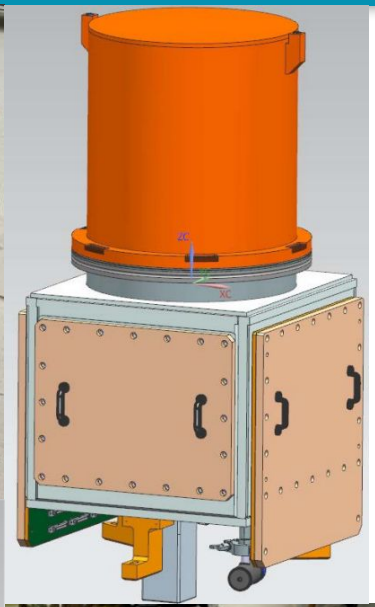
# Perspectives

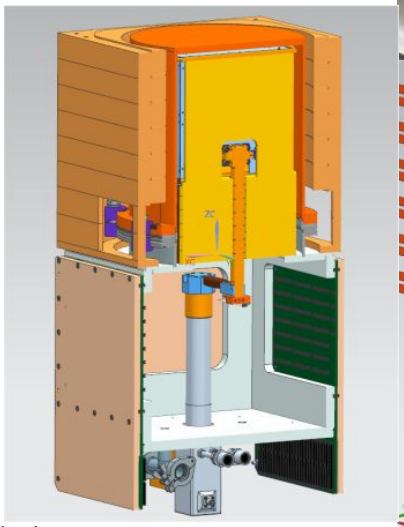
- We have our science detectors and they work!
  Next step: **production** (in progress).

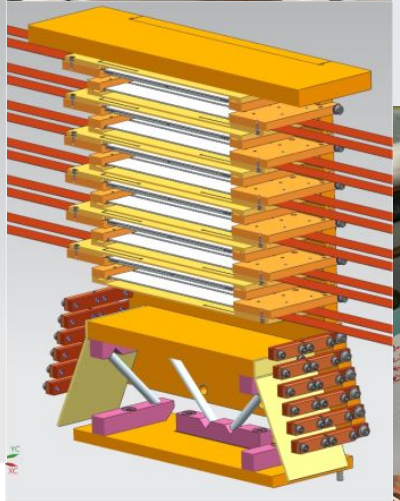
- We are assembling our vessel that will go to SNOLAB.
  - MINOS (standard shield): 10000 dru
  - MINOS (extra shield): 3000 dru
  - SNOLAB (final setup): **5 dru**.

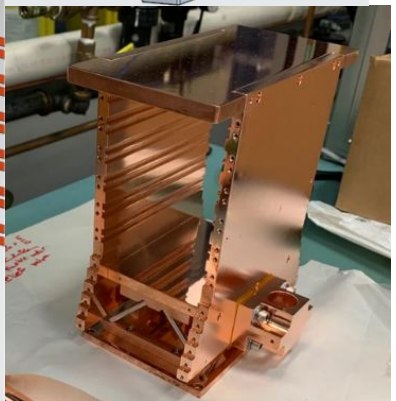
- Vessel is at Fermilab,
  ready for testing
  prior to travel.











# Perspectives

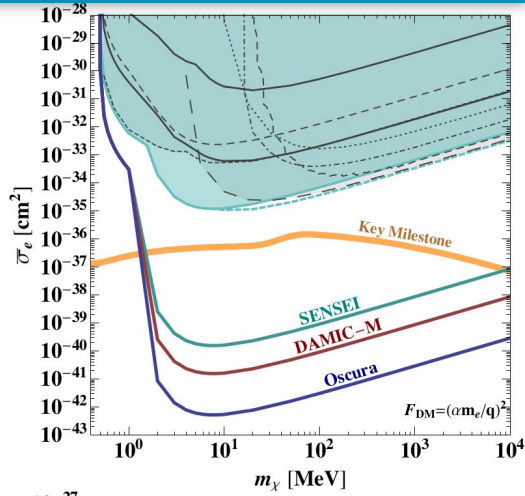
- "Phase 1" system **fully operational** since December @SNOLAB
- Final mass: **100g** (~2g now).
- Deployment in **stages**, increasing mass.
  Results will be presented **gradually**.
- SENSEI should be deployed by
  ~~2020~~ end of 2020 beginning of 2021.

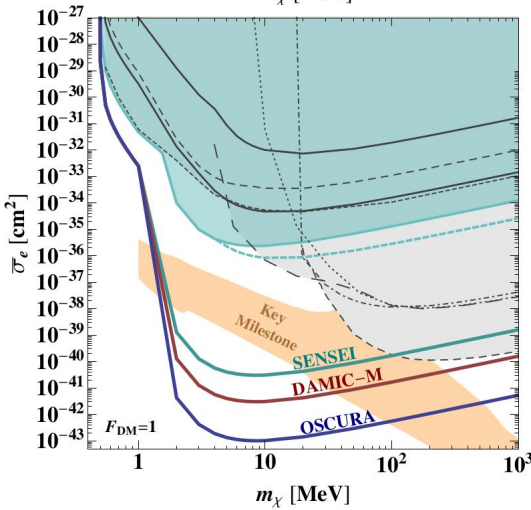
**SENSEI**
- 100g
- 2021

**DAMIC-M**
- 1kg
- ~2024

**OSCURA**
- 10kg
- ~2027

Sho Uemura,
Kevin Kuk
and
Guillermo Moroni
@SNOLAB
December 2019

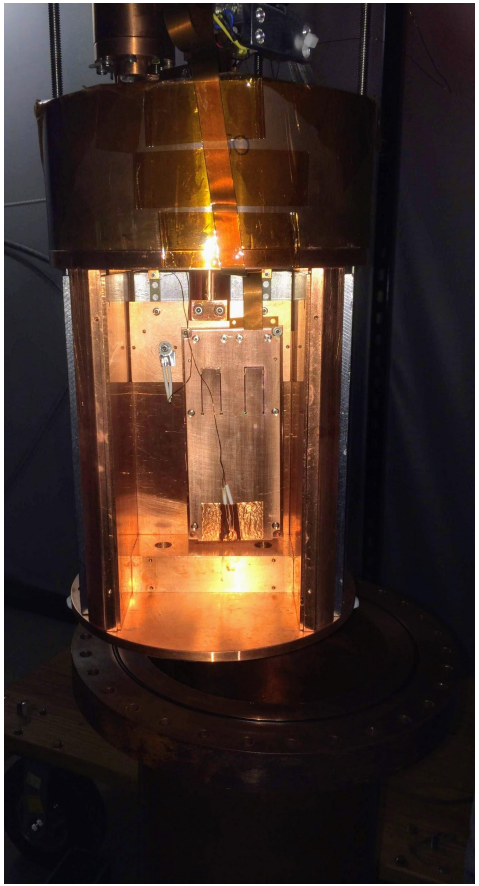


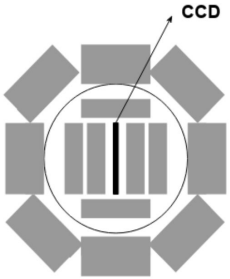



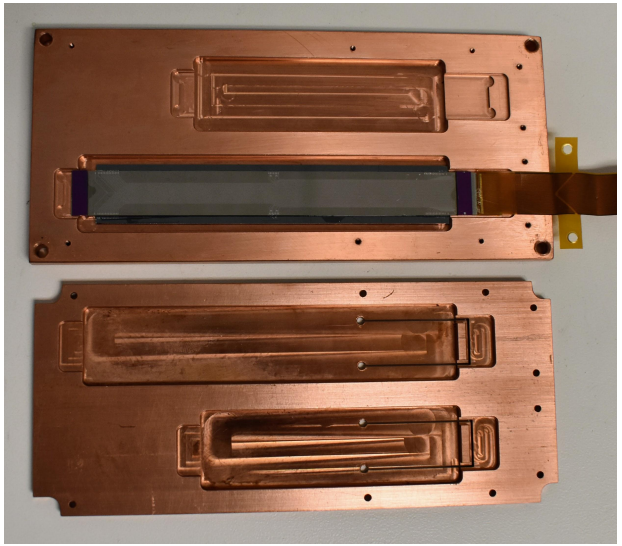
# THANK YOU!

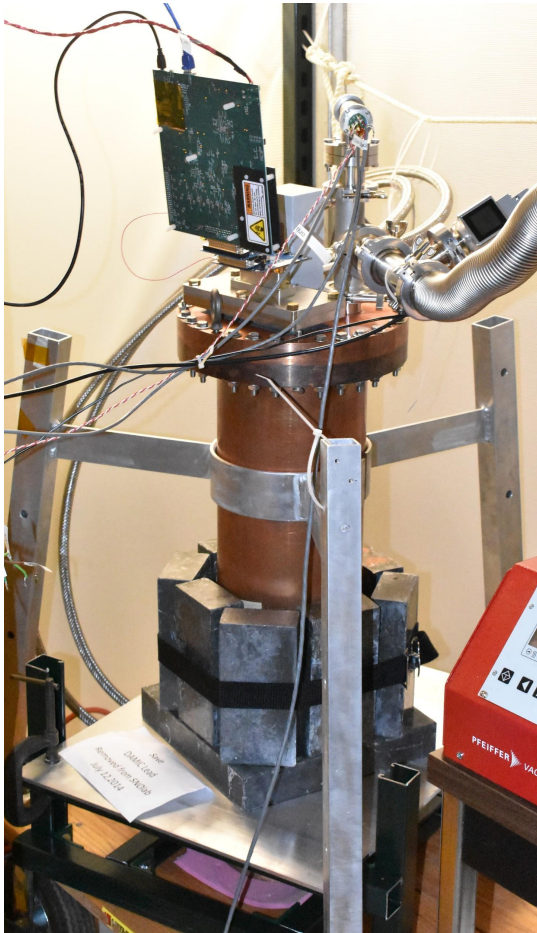
# BACK UP SLIDES

# MINOS shielding







# References

[1] Tiffenberg, Javier, et al. "Single-electron and single-photon sensitivity with a silicon Skipper CCD." Physical Review Letters 119.13 (2017): 131802.

[2] Crisler, Michael, et al. "SENSEI: first direct-detection constraints on sub-GeV dark matter from a surface run." Physical Review Letters 121.6 (2018): 061803.

[3] Abramoff, Orr, et al. "SENSEI: Direct-detection constraints on sub-GeV dark matter from a shallow underground run using a prototype skipper CCD." Physical review letters 122.16 (2019): 161801.

[4] Barak, Liron, et al. "SENSEI: Direct-Detection Results on sub-GeV Dark Matter from a New Skipper-CCD." arXiv preprint arXiv:2004.11378 (2020).

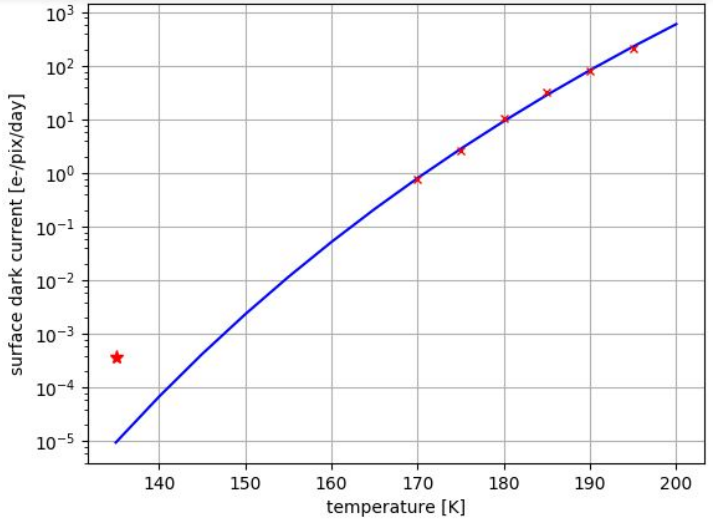
[5] Essig, Rouven, et al. "Relation between the Migdal Effect and Dark Matter-Electron Scattering in Isolated Atoms and Semiconductors." Physical Review Letters 124.2 (2020): 021801.

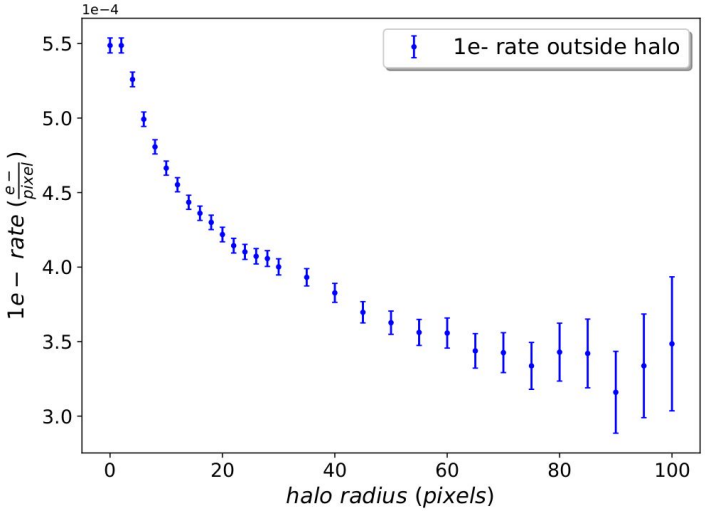
# Our last result: single electron event rate

- A 1e- rate excess is found extrapolating from higher temperatures **assuming only surface DC**.

- Extrinsic or intrinsic sources?

  - RO stage luminescence, other DC
  - Diffusive light, related to high energy events



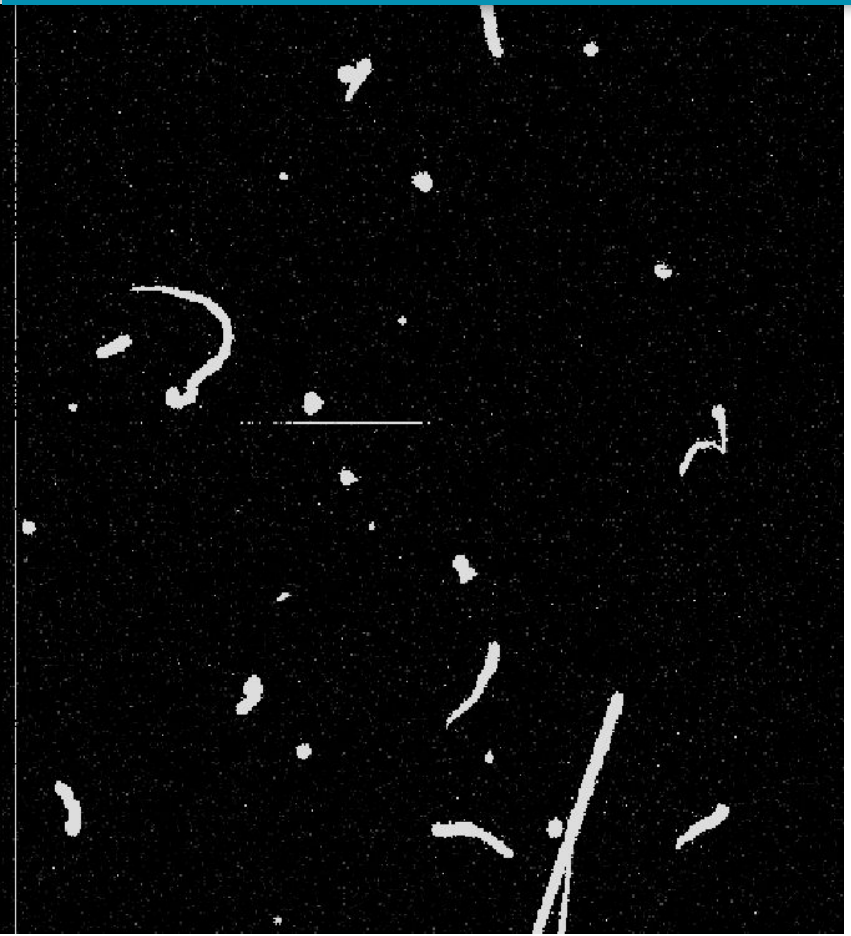



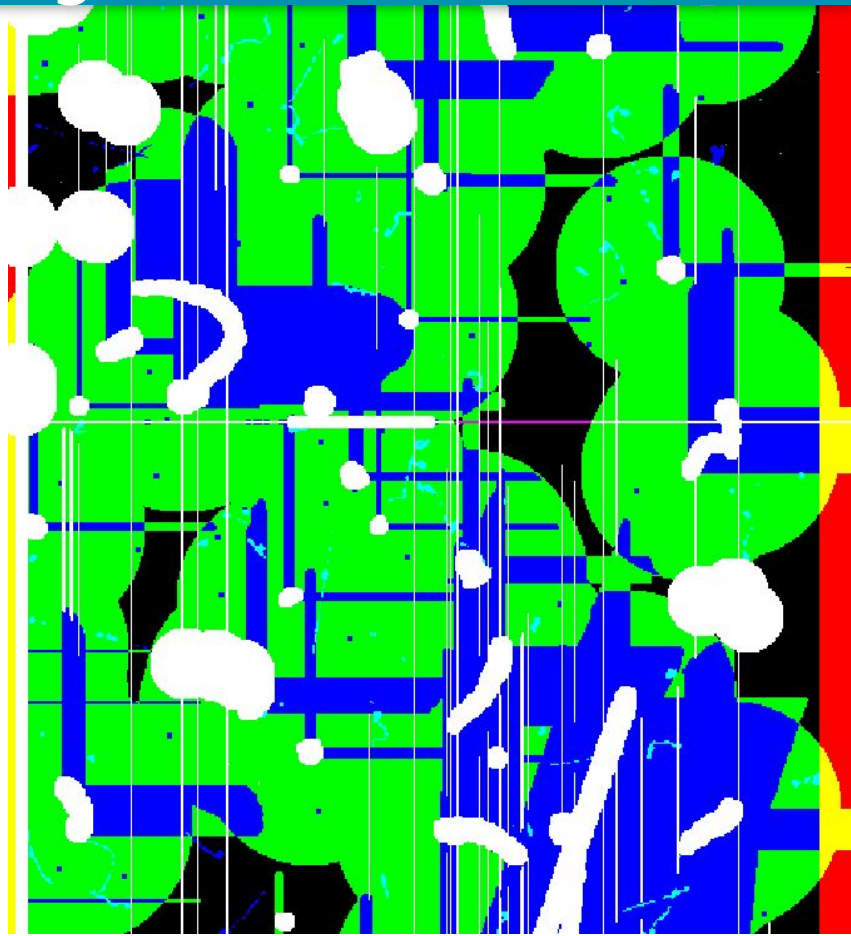

- Spatial correlation between high energy events (>360eV) and 1e- events.

- Low-energy photons? From copper module, CCD or both?

- Can we mask it up to 100%?

# Sample image





# 1e- rate vs. shielding

- We have data with and without the outer ring of lead bricks
- Factor of 3 reduction in the rate of high-energy tracks $\rightarrow$ factor of 3 reduction in the $1e^-$ rate
  - There is some mechanism by which ionizing radiation generates charge uniformly in our CCD
  - Better shielding will very likely further reduce our $1e^-$ rate